Method of operation and construction to place parallel fibres under required equal tension.

The invention is concerned with a mode of operation and a construction for the unwinding of yarn reels, bobbins and spin cakes from a creel (rack with reels) and placing these yarns under the same correct tension as each other for the purpose of supplying them to a machine for further processing.

For the manufacture of textile products, especially the processing of high-quality industrial fibres such as glass fibres, "ARAMIDE" fibres and carbon fibres, it is important that the tension of the fibres in the end product are all the same as each other. After all, during the manufacturing of a semifinished product or an end product the fibres are generally introduced with a particular prestressing force, this prestressing force fades away as a result of shrinkage after the product is finished. If the fibres were to have different diameters, as is often the case with spun threads, the fading away of the strength after the product is finished leads to different rate of shrinkage of the separate threads, whereby the flatness of the product is adversely affected.
If during the process the fibres are fixed by impregnation with synthetic resin, as is usual for the manufacture of so-called prepregs, unidirectional material or the winding under tension round a (temporary) carrying core, it can be advantageous to bring them to a level of prestress to be further determined.
The correct and equal tension of all the fibres is extremely important if the tensile strength of the fibres is critical for the correct working of the end product, as is the case with wound synthetic flywheels, high-pressure tanks, and synthetic rotors for ventilators and generators, among other things.
It is exactly these applications whereby the creel is directly coupled to the construction that takes care of the processing of the fibres into the semifinished product or end product.

Up until now, by preference people carry this out by equipping each individual end point with a precise (electronically controlled) brake that regulates the exit force. The braking of such a creel is more expensive as the exit force of several end points must be regulated. It must be noted that it is not possible with this equipment to regulate the exit tension, but only the exit force. The braking mentioned is usually generated by measuring the deflection of a so-called dancer roller around which the fibre is led strengthening or weakening the working of the brake based on this measurement. Only with very homogenous fibres of equal diameters is the strength in the fibre a measure for the tension in the fibre.

The operating method in question does not have the above mentioned disadvantages of the current technical possibilities and can be advantageously implemented in situations where there is a need for an exact tension regulating, where many exit points are required simultaneously and with a high degree of accuracy, such as the manufacture of wide prepregs for the aircraft industry, printed circuit board manufacture and the manufacture of extremely lightweight sandwich panels. In those cases it is not unusual for a fibre bundle width of 1mm to contain 1,000 to 1,500 fibre bundles.

The aim of the invention in question is, in a simple and inexpensive way, to bring about that the out-fed fibres all have the same tensile stress within narrow tolerances independent of the randomly fluctuating force with which they are introduced. While the invention is also suitable for the transport and tensioning of materials with a more continuous structure such as on a production line for paper, plastics, composite materials or textiles, the invention will be further explained here by means of it's preferred application in the sphere of fibre transport.

SUMMARY OF THE INVENTION

The method of operation

From experiments it appears that the coefficient of friction f in the case of sliding friction between a textile fibre and the surface of a roller shows a greater constancy than that of a stationery friction. Thus a small difference of speed between fibre and driving roller appears to have a stabilising effect on the transfer of a constant drive power. With many pairings of materials this drive power is less than the maximum drive power that can be transferred without slippage. Also, to avoid this phenomenon and remain holding full grip a so-called Anti-Blocking System (ABS) has been developed for the motor industry for the purpose of being able to use the maximum braking power for as long as possible.

In the mode of operation according to the invention the very aim is to limit the drive power to a maximum level that can be compared to a similar maximum level of the adjacent fibre bundles. According to the theory of elasticity tension in warp fibres or fibres of a prepreg or fabric can only arise in the case of an equal elasticity of the warp threads of fibres. According to this reasoning it is so that if the passage of the end product via a roller can take place slip-free with a peripheral velocity v_2 and the supply of all warp threads can take place slip-free with a velocity v_1, the elasticity between out-feed and supply for all warp fibres is equal.
This reasoning likewise goes for slipping rollers if v_1 is the velocity of the fibre supply and v_2 the velocity of the fibre out-feed. The speed of the rollers thereby becomes unimportant. In that case the value of the elasticity $\varepsilon = (v_2 - v_1)/ v_1$. The fact is that the product is transported over the out-feed roller with the same velocity at every point where the fibre touches the circumference of the roller. We call this the production velocity v_2.

So at each point on the circumference of this roller a surface can be imagined that lies in the rotation axis of the roller and that is also at right angles to the sectional plane of the product so that the condition of equal relative velocity is fulfilled.

Equal tension of each and every fibre requires an equal elasticity to be determined beforehand, so that at the start of the production process a vertical plane must exist where all fibres are supplied with each of them travelling at the same velocity v_1.

Because transport of fibres by means of transporting them over a roller can only take place without slippage if the fibre tension before the roller and after leaving the roller is virtually the same, the fibre tension is by preference built up from 'nil', at any rate virtually nil.

As is well known this construction can be realised by drawing the fibres over a number of stationary rods. For example this is described in the American patent US3253803. The building up the required tension then takes place by partly encircling the rod according to the formula $F_2 = F_1 \times e^{f \times \alpha}$, whereby α is the angle at which the fibres cover the surface of the rod.

Because the coefficient of friction f depends on the properties of the material between the elements that cause the friction, here the fibre and the rod surface, and can therefore only be influenced to a limited extent, a higher friction required can be achieved by increasing the encircled section α of the rod. In the application in question the fibre bundles are lying next to each other so that the circumference of the rod is only usable to a limited extent.

The invention in question then also includes the increasing of the angle of contact by the application of more rods whereby the bundles of fibre can go round each rod to a maximum of almost 180°.

A further improvement to the invention is created by rotating the rods in the direction of the transport with a peripheral velocity that is marginally smaller than the velocity of the fibre.

This is possible with the aid of a design that strongly resembles the mode of operation described above on the understanding that the peripheral velocity of the rollers in this case is marginally higher then the required velocity of the bundles. Such a mode of

operation is described in the American patent US5957359 in which the tension decreases through the part encircling of one roller. The patent mentioned makes use of the partial encirclement of only one roller over which the fibres slip whereby the tensile strength in the fibres is reduced whereby a tensile strength difference between the fibres lying next to each other of a maximum of approximately 100% can be equalised. In addition by partly encircling a subsequent roller it can be assumed that the fibres should not slip over this last roller because of a greater (part) encirclement of the roller. This is at the least dubious because in the case that no slippage of the fibres takes place on this roller the fibres will move over the roller following a helical line. In any case with this well-known construction it is only possible to create a relatively very limited final tension. In addition this well-known construction has the disadvantage that all fibres must be manually introduced one by one over the set of rollers.

The invention in question does not have these disadvantages because each fibre or bundle of fibres has as it were its own imaginary surface across the entire installation in which all the necessary processing takes place. What is new is the idea that with the use of several rollers the tension in different fibres that at the start of the process may have very large differences in value from each other, irrespective of the starting tension and the differences from each other, after a particular number of rollers and remaining in their own flat plane, is reduced to a tension level that is virtually nil. The tension differences to be reconciled, the required accuracy, the coefficient of tension and the total (part) encirclement determine the number of rolls. The number of fibres that are simultaneously available in the process has no effect on the process, but only on the total required pair and the strength of the construction. The invention consists of the fact that this tension reduction can be used in the first part by transporting the fibres to the second part, a slip lock unit, out of which they are, in the third part, transported across a number of rollers and each brought to the required equal tension. The slip lock unit is constructed such that the fibres cannot slip in the unit. Control of this tension can be simply carried out automatically by measuring the result of a measuring roller under prestress preferably resting at right angles to the fibres moving over it and hereupon changing the total (part encirclement of the rollers of the first processing phase in such a way that the result of the measuring roller returns to the required state. The in absolute

values very small difference in tension before the unit manifests itself as a very small difference in velocity. Because the starting velocity preceding the third part is near enough the same for all the fibres, and the take-off velocity for all fibres is the same for each one because of the nature of the process to be next carried out (for example a wrapping machine, an impregnation process or loom), the final tension of all the fibres is near enough the same. The absolute difference between each of the tensions before the slip lock unit is determined by the difference in tension at the start of the process, the number of rollers, the coefficient of friction f and the angle of contact α across all rollers and can therefore b reduced to a required minimum. So with the invention it is possible to make a construction whereby for a large number of fibres with an arbitrary level of tension and an arbitrary difference in tension between them the tension of the fibres is reduced simultaneously to near enough tension free, which in the slip lock unit is converted into a near enough equal velocity of the each and all of the fibres. From the slip lock unit, in a well-known way, by applying a difference in velocity, the tension on all the fibres can be increased again if required. If people do not want to increase tension it is possible in the following process to have the slip lock unit driven by the tensile strength on the parallel fibres between the slip lock unit and the following process. In that case as well the tension of each fibre will not vary. Because of the equal elasticity between the slip lock unit and the place where the fibres become connected to each other in the following process in the construction the final tension for all fibres is the same to a high degree of accuracy.

The invention also provides an improvement to a slip lock unit by applying an endless belt with elastomer properties, which is transported over one part of the circumference of a roller. The fibres are pressed onto the roller by the belt, without a great deal of deforming arising in the fibres or in the belt or the surface of the roller. The large surface nevertheless makes it possible to apply a large frictional force to the fibres. The small deformations make it possible to transport the fibres through the unit without slippage and at a constant and known velocity, whereby the unit is not very sensitive to the tensions present in the fibres.

In summary the mode of operation consists of the following three processing phases:

1. Reducing the tension of the fibres from an arbitrary individual stress level to a stress level of nil or near enough nil.
2. Slippage free transport of the fibres through a slip lock unit at a known velocity determined in advance.
3. Building up the tension of each fibre equally from the nil stress level to the required collective stress level.

By means of this mode of operation it can be realised that all the bundles of fibres lying next to each other are brought from an arbitrary stress level to a stress level of near enough nil, whereby a new mutually identical tension situation is realised and by means of a slip lock unit an identical transit of the bundles of fibres is achieved. The building up of the tension after the unit must take place by degrees with the aid of a number of rollers that, as a consequence of a deliberate difference in velocity from the bundles of fibres, slows these down until the correct tension is achieved. Because the distance to be travelled is the same for all bundles, identical elasticity comes into being whereby an identical tension is guaranteed. Collectively processing the bed of fibre bundles obviously requires sufficient stiffness of the rollers. The diameter of these rollers is therefore preferably chosen to be not too small. This also has the consequence that the bending stress of the individual fibres in the bundles of fibres remains fractionally low so that breakage of fibres in the construction is ruled out and the ends of the fibres even after any preceding breakage will simply be carried along in the fibre bundle package and therefore not cause any snags (the rolling up of individual fibres in a bundle of fibres as a consequence of the frictional working of stationery guiding elements).

The construction

The invention further encompasses an arrangement for the execution of the mode of operation described above. Such an arrangement is according to the invention provided with a first part (de-tensioner) with at least one but preferably a number of cylinder shaped rotating elements (rollers) of which each roller can rotate on its own axle with a peripheral velocity that according to a preferred realisation is higher than the required transport velocity whereby the fibres to be transported are preferably led round the

rollers in a loop in order to realise an encirclement of these rollers whereby a greater total angle of contact can be achieved than would be possible with only one roller, and a second part (slip lock unit)with at least one roller with a rigid or at least relatively non-distortable surface wherein a part of the transport, by pairing with an accompanying pressure element, preferably consists of an endless transport belt or a roller with compressible surface that exerts a frictional force on the fibres between the surfaces so that they are transported without slippage at the transport velocity of the roller with a rigid surface and therefore determines the velocity of the transport of the fibres, and a third part (tensioner) provided with rollers whether revolving or not around which by preference the surrounding fibres are drawn so that a build up of the tension of the fibres is obtained.

In order to guarantee good working of the de-tensioner and the tensioner it is important that the transport velocity of the rollers of the de-tensioner is always greater than the transport velocity of the slip lock unit and the transport velocity of the rollers of the tensioner are always smaller than the transport velocity of the slip lock unit. This can be simply realised by choosing that the diameter of the rollers of the de-tensioner is greater than that of the roller of the slip lock unit and the diameter of the rollers of the tensioner is smaller than that of the roller of the slip lock unit and at the same time keeping the speed of revolution of all the rollers the same.

In order to realise the good working of the arrangement in a simple way it is preferably constructed of two parallel frame plates connected to each other via spacer blocks and equipped with an identical pattern of bearings in which the rollers mentioned can be lowered.

One arrangement with a very good ease of operation and suitable for a large diversity of frictional properties can be achieved by the (part) encirclement of a larger number of identical rollers whereby all the uneven numbered rollers are placed on a first part of the frame above each other at a distance from each other that is twice the diameter of one roller and all the even numbered rollers are placed on the second part of the frame above each other all at the same distance whereby through the approaching of the first part of

the frame by the second part of the frame the even numbered rollers can pass over the uneven numbered rollers without them touching each other in such a way that the rotation axles of all the rollers maintain there parallelism, all with each other.

With such a form of construction of the invention through the maximum distancing of the frame parts from each other a passage between the set of uneven rollers and even rollers exists through which the one-off throughput of fibres is considerably simplified. With the approaching of the first part of the frame by the second part of the frame gradually a (part) encirclement of all the rollers comes into being that through a further approach can be increased to a value that is determined by the product of the number of rollers and half the circumference of one roller.

The arrangement also provides reduction in wear and tear to the fibre and to the equipment as a consequence of the continuous slippage between the cylinder shaped elements and the fibres, by driving the cylinder shaped elements in the third part of the arrangement with a transfer velocity that is slightly less than the required throughput velocity of the fibres.

Further wear and tear can be avoided advantageously by providing the rollers with a wear-resistant layer for example achieved by hardening the surface. One important positive consequence of the preferred construction according to the invention is also that through the slippage between the bundles of fibres and roller surfaces a particular maximum friction by the cylinder on the bundle of fibres can be transferred and therefore the amount of the slippage is unimportant for the correct working of the arrangement. This means that the rollers that rotate in relation to the fibre bundles with slippage do not have to be completely round and can therefore be constructed simply and cheaply.

Because the diameter of all the rollers can be chosen freely the construction based on the preferred arrangement of the invention is insensitive to the arising of the snags mentioned earlier and breakage of the fibres during their passage through the construction is ruled out.

The invention is discussed below using the illustrations. These illustrations must only serve as explanations about the invention in question and must not be taken as restrictive.

Figure 1 shows a schematic illustration of the physical principle upon which the invention is based.
Figure 2 shows a schematic illustration of the entire construction according to the essence of the invention.
Figure 3 shows a schematic illustration of the de-tensioner and the slip lock unit according to the invention, whereby the construction is in a state whereby ribbons, threads, filaments, fibres or bundles can be simply transported in the construction.
Figure 4 shows a schematic illustration of the de-tensioner and the slip lock unit according to the invention, whereby the two parts of the frame are moved towards each other with respect to the position in Figure 3 and the ribbons, threads, filaments, fibres or bundles are in contact with a part of the circumference of the rollers.
Figure 5 shows a schematic illustration of the de-tensioner and the slip lock unit according to the invention, whereby the two frame parts are moved further towards each other with respect to the position in Figure 4 and the ribbons, threads, filaments, fibres or bundles are in contact with a larger part of the circumference of the rollers.
Figure 6 shows a schematic illustration of the tensioner according to the invention.

Figure 1 shows a bundle of fibres that is moving over a driven roller at a particular velocity (v). The bundle of fibres partly encircles the roller at an angle (α). The roller rotates in the direction shown at the peripheral velocity ($\omega \times R$). The coefficient of friction of the roller surface amounts to (f). F1 is the tensile force in the bundle of fibres before the roller. F2 is the tensile force in the bundle of fibres after the roller.
Now one of three situations can arise:

1. $(\omega \times R) > v$
   The peripheral velocity of the roller is greater than the velocity of the bundle of fibres. In this case the tension in the bundle of fibres is reduced. Because the sliding friction is independent of the sliding velocity the difference in velocity

between fibre and roller surface is not important. This situation arises at the location of the de-tensioner.

(F1>F2).

2. $(\omega \times R) = v$

   The peripheral velocity of the roller is equal to the velocity of the bundle of fibres. Now slippage free transport of the bundle of fibres takes place. This situation arises at the location of the slip lock unit.

   (F1=F2).

3. $(\omega \times R) < v$

   The peripheral velocity of the roller is less than the velocity of the bundle of fibres. In this case the tension in the bundle of fibres is increased. Also in this situation the difference in velocity has no effect on the friction between the fibre and the roller surface. This situation arises at the location of the tensioner.

4. (F1<F2).

Figure 2 shows in which way a single fibre coming from one of the exit points (30i to 30iii inclusive) and in the virtual plane represented by the illustration goes through all the processing steps via a free-turning roller (31) that serves to make the (part) encirclement for all parallel fibres the same to the de-tensioner in the construction. This is a first processing step by transporting the fibre alternatively left and right over the rollers (16) and (5) whereby because of the slippage of the fibre with respect to the periphery of the roller, the force in the fibre is further reduced by each partial loop until a negligible force remains. The sum of the remaining forces of all parallel fibres can be determined using a measuring roller (32) that is pressed more or less at right angles on the fibres that are travelling from the de-tensioner to the slip lock unit and of which the depression or the pressing force determines this remaining force.
In the slip lock unit the fibres are pressed between the roller (7) and the endless belt (11) so that the transport velocity of all fibres is determined by the peripheral velocity of the roller (7). In the next and third processing step, the so-called tensioner, by equal lengthening of all parallel fibres as a consequence of the alternately left and right pulling of the fibres with slippage over a number of rollers (25) and (29) an equal and desired

tension is built up in all the fibres. The tensile force mentioned is supplied by the following process, for example by a warp beam winding device.
This tension results in a sum of the forces of all the fibres, which force can simply be determined on the basis of a measuring roller (33) that is pressed more or less at right angles on the fibres that are travelling from the tensioner to the next process and of which the depression or the pressure force determines the remaining force in the fibres.

Figure 3 is a schematic illustration of the de-tensioner and the slip lock unit in a state whereby the ribbons, threads, filaments, fibres or bundles (12) can be fed easily through the construction. The fibres (12) come from a supply (not shown) and are transported between the rollers (5, 16). The fibres are then led over a roller (7), whereby the fibres are pressed onto the surface (8) of the roller by a belt (11). This combined action of roller (7) and belt (11) forms a slip lock unit. The belt (11) is tensioned by rollers (9). The rollers (5) are supported on bearings connected to frame part (1) and the rollers (16) are supported on bearings connected to frame part (2). Both frame parts can move with respect to each other whereby a guide (3) only permits one degree of freedom.

Figure 4 is a schematic illustration of the de-tensioners and the slip lock unit in a state whereby the ribbons, threads, fibres or bundles (12) are fed through the construction and whereby the frame parts (1, 2) have been moved towards each other as compared with the situation in Figure 3. The fibres (12) now make contact with a part of the surface (6, 17) of the rollers (5, 16). The peripheral velocity of the rollers (5, 16) is greater than the throughput velocity of the fibres, whereby the arbitrary forces in the fibre bundles from the various exit reels are decreased by partially looping round a first slipping rotating roller, which decrease is continued by the following slipping rotating rollers so that the bundles of fibres are transported with a minimal and negligible level of force and thereby also a minimal and negligible relative difference in forces between a precisely cylindrical rotating roller (7) with a peripheral velocity determined before hand and kept constant on the one hand and an endless transport belt (11) covered with a material that offers sufficient resistance against slippage placed and supported against the roller on the other hand whereby a slippage-free drive of the bundles of fibres (13), by now brought to a very low tension, is achieved.

Figure 5 is a schematic illustration of the de-tensioner and the slip lock unit in a state whereby the ribbons, threads, fibres or bundles (12) are transported by the construction and whereby the frame parts (1, 2) have been moved closer to each other than the situation in Figure 4. The fibres (12) now make contact with greater part of the surface (6, 17) of the rollers (5, 16). The angle of the encircled arc α of the fibres on the rollers has become greater, whereby per roller, under constant conditions, more tension is built up in the fibres.

Figure 6 is a schematic illustration of the tensioner, whereby the ribbons, threads, filaments, fibres or bundles (24) are in contact with a part of the circumference (26) of rollers (25). The rollers have a peripheral velocity that is less then the throughput velocity of the fibres (24) whereby the tension in the fibres is increased by each roller according to the principle shown in Figure 1. As a consequence of the lengthening of the fibres between the slippage-free supply and take-off over an equal distance for all the bundles, the tension of all the fibres is and remains equal. Obviously, where the tension is momentarily higher a momentarily greater elasticity will come into being with a lower normal force in the (part) encirclement as a result, which immediately has a decrease in the friction and therewith the tension as a consequence. The fibres (27) leave the construction to be further dealt with by a process that is not described here. In this arrangement also the frame parts (21) and (22) can move in relation to each other, whereby the guide (23) only permits one degree of freedom.